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Quarterly Technical Summary

General Research

15 August 1965

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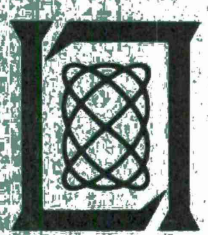
Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts



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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

INTRODUCTION

This Quarterly Technical Summary covers the period from 1 May through 31 July 1965. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Stanley J. Wisniewski
Lt Colonel, USAF
Chief, Lincoln Laboratory Office

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DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 May through 31 July 1965 for the General Research Program of Division 2. Separate progress reports on the Ballistic Missile Re-entry Systems, Graphics and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25 and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

S. H. Dodd
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1965

PUBLISHED REPORTS

Technical Note

TN No.				DDC and Hayden Nos.
1965-26	Solution of the Matrix Equation (d/dt) X(t) = A(t) X(t) + X(t) B(t) + U(t)	M. Athans	29 June 1965	DDC 618392 H-659

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2251	Estimation of Signals Containing Unknown Parameters: Comparison of Linear and Arbitrary Unknown Estimates	D.J. Sakrison	Accepted by J. Soc. Ind. Appl. Math.
2544	Telling a Computer How to Evaluate Multidimensional Situations	D.B. Yntema L. Klem	Accepted by IEEE Trans. Human Factors Electron.
2555	Reachability of Subspaces	P.L. Falb	Accepted by IEEE Trans. Automatic Control
2562	Magnetic Measurements with Lorentz Microscopy	M.S. Cohen	Accepted by IEEE Trans. Magnetics

Meeting Speeches*

MS No.			
1333A	APEX – A Lincoln Laboratory Approach to Man-Computer Cooperation in Problem Solving	D.B. Yntema J.W. Forgie	Seminar, M.I.T., 11 May 1965
1372	Formal Aspects of Programming Languages	J.A. Feldman	International Federation for Information Processing Congress, New York, 24-29 May 1965
1401	Graphical Communication in a Time-Sharing Environment	L.G. Roberts	

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Unpublished Meeting Speeches (Continued)

MS No.			
1378	The Operation-Oriented Approach to On-Line Interaction Between Scientists and Computers	D.B. Yntema	IEEE, Human Factors in Electronics, Boston, 7 May 1965
1405	Homogeneous Matrix Representation and Manipulation of N-Dimensional Constructs	L.G. Roberts	Engineering Summer Conference, University of Michigan, 14-18 June 1965
1420	A Graphical Service System with Variable Syntax	L.G. Roberts	ACM Programming Language Conference, San Demos, California, 8-14 August 1965

DIGITAL COMPUTERS
GROUP 23

I. COMPUTER SYSTEMS

A. TX-2 Optical Scanner

Programs in existence have been up-dated and a new input routine for Roberts' picture processing programs has been written for use with the image dissector camera. Three-dimensional objects, documents and pictures have been successfully scanned and read into TX-2.

B. Typewriter-Keyboard Consoles

All the known logic defects in the two existing consoles have been eliminated and a third console is being built.

C. V-Memory Multiplexer

Mechanical design of all assemblies has been completed and fabricated parts have been received from the shop. Two of the three logic boxes to be used for the V-Memory Multiplexer are approximately 50 percent complete. The plug-in unit card layouts have been sent to the vendor, and a number of logic flat packs have been received.

D. TX-2 Tape System

Four new tape drives and one old one are presently mounted in the TX-2 room. A series of logic package failures as well as considerable trouble with the tape motion control system have frustrated efforts to put a drive on-line with acceptable reliability. Recent progress has given some hope that at least one drive may be put on-line permanently within this reporting period.

E. Xerox Printer

An improved circuit design for the Page Mark Detector has eliminated the one troublesome source of past Xerox failures. Installation of the improved TX-2 Variable Delay packages should eliminate the remaining infrequent troubles with the printer.

F. Integrated-Circuit Systems

Several integrated-circuit systems are now nearing completion. The V-Memory Multiplexer will allow as many as thirty-two 38-bit words from special-purpose devices to be read by TX-2 via the V-Memory system. The V-Memory output distributor will allow 38-bit words to be sent to a number of special-purpose devices. The Executive Timer Register, one of the special-purpose devices connected to TX-2 via V-Memory, will be used in the multi-user facility to allocate time to various users; when the timer runs out an interrupt is sent to the connector, alerting the Executive Program. The Console Number Register is used by a program to select which of several consoles is to be connected. The Console Output Register, via V-Memory, gives a user program the capability of sending information to a selected console for use in experimental hookups.

II. CIRCUIT DEVELOPMENT

A. UHF Switching Transistors

1. High-Speed Silicon Transistors

The final version of the Philco LL-3 UHF silicon switching transistor has proved excellent in all respects. This unit has a base window area of 1.6 × 1.9 mils and uses four 0.1-mil emitter stripes and five 0.1-mil base stripes. A summary of the important parameters follows.

Gain-bandwidth	$f_T > 1$ Gcps for I_c = 0.6 to 90 ma at V_{cb} = 0 volt
Gain-bandwidth	$f_T > 2$ Gcps for I_c = 2.7 to 62 ma at V_{cb} = 0 volt
Input resistance	$r_b' < 10$ ohm for I_c = 1.5 to 27 ma at V_{cb} = 0 volt
DC current gain	>80 at I_c = 10 ma, V_{ce} = 2 volts
Breakdown voltages	$BV_{ebo} > 6.5$ volts at 10 μa
	$BV_{cbo} > 11$ volts at 10 μa
	$BV_{ceo} > 4$ volts at 1 ma

These are all limiting values, not typical ones. The highest measured value of f_T was 4.6 Gcps at 15 ma and 3.0 volts.

Rise-time measurements were also made, with the following results.

	Philco LL-3	Commercial 2N2475
Initial delay	1.2 nsec	1.6 nsec
Rate of rise	32 ma/nsec	11 ma/nsec
Base voltage	1000 mv	1090 mv
Saturation voltage V_{ce} at 48 ma	120 mv	120 mv

A standard SPAT circuit has been fabricated using two LL-3 current-mode stages and a pnp stage containing Texas Instruments germanium planar switching transistors. Delay time through the three stages was 1.8 nsec, which is a considerable improvement over the 5 nsec typically measured for standard commercial transistors.

2. Base Resistance Measurements

Measurement of r_b' continues to be a problem where very fast transistors are concerned. The standard h_{rb} equipment has a tendency to oscillate when high f_T, low r_b' transistors are measured. Equipment modifications will be made in an attempt to eliminate the problem. Meanwhile, a new look is being taken at noise-figure and h_{ie} measurements in an attempt to determine what correlation exists among the various results.

B. Integrated-Circuit Design

The LL-3 transistor design is being modified for incorporation into integrated circuits. Simple T^2L and ECL circuits are being evaluated for high-speed performance. The changes in the transistor to attach the collector connection to the top surface will degrade the performance to some extent. The goal is a delay of less than 1 nsec per stage.

C. Integrated-Circuit Logic Modules

Thirteen integrated-circuit logic modules are now available for use in TX-2 or other equipment. These include a general purpose gate, a gated buffer, a power gate, a clocked flip-flop, single-shot modules, buffer and power inverter modules, a basic flip-flop module, a counter module, two transfer gate modules, a cable terminator module and an indicator-light driver module.

Two TX-2 packages, a positive level output distributor and a positive level input shifter, are also available for interfacing with integrated circuits. Both are designed for use with terminated 93-ohm cable.

D. Integrated-Circuit Evaluation

DC and propagation delay measurements were made on 801 DTL integrated circuits. Nine elements were inoperative, ten failed to meet DC specifications, and nine failed to meet propagation delay specifications. The DC parameters for 133 RTL integrated circuits were also measured, and all met specifications.

III. MAGNETIC FILM ENGINEERING

A. Clean Room

Operational "shakedown" of the clean room is near completion, and evaluation of the room in terms of cleanliness level has begun. While this work will continue, a sufficient level of cleanliness has been achieved to permit concentration on the basic problem of pinholes in thin evaporated films. Attention is currently focused on problems associated with the observation and classification of types and sizes of pinholes as they relate to film thickness and composition.

B. Magnetic Film Characteristics

Film lines with easy axes normal to line direction were found to have as much as 90 percent flux remanence in their hard direction (i.e., parallel to the line), provided their shape anisotropy exceeded their intrinsic anisotropy. Such films also have a storage state with most of the flux normal to the line, and therefore offer possibilities for magnetoresistive sensing.

C. Content-Addressed Memory

A film word has been operated in the content-addressed mode with negative output for 1 mismatch bit, in the presence of 14 match bits, of more than a millivolt and more than twice the positive output from 15 match bits. However, uniformity within films and from film-to-film is unsatisfactory. New masks are being procured to make better use of the film surfaces, and appropriate changes are being made in the vacuum system.

D. Large Capacity Memory

Undesired coupling from word to digit lines, due to line defects, has been examined. Imperfections in the lines will probably have to be held to less than 1 mil in size on the digit line and 0.5 mil on the word line. The best digit lines have been scribed directly in 1000 Å Cu. Some lines made by photographic exposure and etching are good enough for the tester.

The one-million bit prototype stack, with 10 percent of its word lines connected and driven, has been assembled and is being tested. Initial measurements of word noise have been encouraging.

E. Circuit Design

Design of a group-switch circuit for the double-ended diode-matrix word-line-addressing scheme has been completed. Specifications include: 0.1-μsec selection time, minimum cycle time of 1 μsec, and "on" voltage of 0.3 volt, plus inductive drop in leads, for 0.5-amp word pulses.

A single-ended word-line-addressing scheme with transistor selection matrix is being investigated. The resulting lower transient voltages on word lines could reduce word noise.

F. LCM Line Quality

The technology of etching 10-in. 2-mil word lines has improved to the point where less than 1 percent of the 350 lines are open. This has been made possible by a good negative (scribed in-house), filtered photoresist application under clean room conditions, and the absence of large pinholes in the deposited permalloy and copper films. While 10 to 100 small pinholes (median size 0.4 mil) generally exist, only about 10 percent are 1 mil or larger.

IV. SYSTEM PROGRAMMING AND APPLICATIONS

A. INSIGHT

A debugging system, INSIGHT, that places heavy emphasis on graphical communications is being developed for TX-2. The most important characteristic of this system will be its ability to display the dynamics of the state of a program and the topology of program-control flow. Communication with user programs will be possible through these displays as well as through displays of source language statements. A text-editing program, which displays selected excerpts of source language statements and permits modifications via a keyboard and light pen, has been completed. Work has begun on a program for displaying graphs of run-time program-control flow; list structure models for these graphs have been automatically generated from tables of "jump-from, jump-to" address pairs.

Specifications have been drawn for a hardware modification that will allow automatic detection of jumps and skips in program-control flow. This modification will permit fully transparent flow tracing of users' programs in either conventional or time-sharing environments without the use of a time-consuming machine-code simulator. In addition, slight modifications to already existing hardware will permit transparent breakpoint testing, data reference trapping and arithmetic overflow detection. All these features will be used independently, in any combination, by each time-sharing user.

B. VITAL

Progress on VITAL, the compiler-compiler for the TX-2, has advanced appreciably in this period. The system is being designed to be compatible with work, currently under development, on graphical language and debugging systems. A preliminary version should be completed during the next reporting period.

COMPUTER COMPONENTS
GROUP 24

I. ELECTRON TRANSPORT

A. Oxidation of Aluminum

Much of the previously reported nonreproducibility in the work function changes of aluminum undergoing thermal oxidation has been found to be caused by water vapor. The water vapor apparently arises from interaction of clean, dry oxygen with the walls and pumps of the vacuum system. Recently, it has been possible to minimize the water-vapor effects by using traps within the system, and several important results have been found: (1) The major change of work function $\Delta\varphi$ of aluminum with oxygen pressure P is due to a quasi-reversible effect such that $\Delta\varphi \propto \ln P$. Therefore, to a first approximation, the work function of the oxidized surface is unchanged from the clean aluminum surface. This would be expected if it can be assumed that surface states do not play a significant role in determining barrier heights. (2) The constant of proportionality in the above equation can be related by thermodynamics to the amount of charge transferred per molecule in a reversible surface reaction. Agreement has been found for a charge transfer of one electron per oxygen molecule; agreement cannot be found for an integral charge transfer per oxygen atom. This is justification for a physical adsorption mechanism, and such physical adsorptions usually have low enough heats of adsorption to be quasi-reversible as opposed to a nonreversible chemisorption process involving dissociated molecules. (3) Questions are raised as to what fraction of the total oxygen uptake is due to the above reversible process and what fraction is due to actual oxidation. This will be investigated further using a quartz crystal microbalance.

B. Thin-Film Metal-Metal Oxide Triode

A thin-film triode fabricated from Al and Al_2O_3, having a power gain of ~5, was described in the last Quarterly Technical Summary report (15 May 1965, DDC 619676). Improved and automatic testing equipment has now been built, and currently fabricated triodes do not show gain on this equipment. The reasons for lack of gain are thought to be understood, and attempts to duplicate the earlier triodes are in progress.

II. MAGNETIC FILMS

A. Anisotropy Spectrum of Permalloy Films

Using the recently completed automatic "H_k-tracker," the relaxation time $\tau = \tau_o e^{Q/kT}$ for realignment by 90° of a structural anisotropy in Permalloy films has been measured for three distinct processes. For nonmagnetostrictive films deposited between 37° and 200°C and measured at the same temperature without removal from vacuum, the measured values of τ_o, Q and the contribution ΔH_k to H_k are summarized in Table I.

TABLE I

MEASURED VALUES OF τ_o, Q AND ΔH_k FOR THREE FUNDAMENTAL ANISOTROPY PROCESSES IN NONMAGNETOSTRICTIVE PERMALLOY

Temperature Range (°C)	τ_o (sec)	Q (ev)	H_k (oe)
37 to 75	10^{-4}	0.37	0.07
50 to 200	2×10^{-3}	0.32	0.20
100 to 200	0.2	0.21	0.25

B. Bottom of Spin-Wave Spectrum

The energy $\hbar\omega_{\vec{k}}$ at the bottom of the spin-wave spectrum in a ferromagnet determines the nature of possible spin-wave instabilities, and therefore is a crucial factor in resonance at high microwave power. For a thin film with bias field H in the film plane, the spectrum is distorted from its bulk value essentially because of the creation of noncanceling surface poles. From the theoretical spectrum based on a "thin-film approximation,"[1] the bias field H_b and wave number k_b at the bottom of the spin-wave manifold have been calculated. In addition, the critical thickness d_c (at which spin-wave instabilities change from first to second order) has been obtained. These results are in fairly good agreement with experimental determinations of H_b and d_c by Comly and Penney.[2]

C. Origin of Quadrature Flux in Magnetic Films

Several authors[3-5] have observed flux switching in quadrature with a small AC excitation field applied to a magnetic film while a DC bias field $\vec{H}$ was simultaneously applied $\perp$ to the AC field. For quadrature flux (QF) detection, $\vec{H}$ must usually be nearly $\parallel$ to the hard axis; for some films, QF is also found for $\vec{H}$ near the easy axis. At least four different mechanisms have been proposed to explain the observed easy and hard axis QF in magnetic films: irreversible switching in regions where the net field crosses the tip of an (1) uniaxial[3] or (2) complex biaxial[6] asteroid; (3) negative anisotropy regions[4]; and (4) ripple rearrangement.[5] The present work supports the last model. QF was measured with a bias field $H = H_k/2$ at 135° to the positive easy direction and an AC field $\parallel$ to $\vec{H}$ ($\perp$ to $\vec{M}$). The result, for films which do not switch by walls or other incoherent mechanisms before $H = H_k/2$, is that the maximum QF has the same value as in the usual arrangement with $\vec{H}$ along the hard axis. This result would be expected from the ripple rearrangement model, since the maximum ripple amplitude occurs when the field point is anywhere on the unstable portion of the uniaxial asteroid. In addition, the QF was measured at 180° and found to be identical to the QF at 90° but displaced in field by $2H_k$, as predicted by the ripple model. However, in this case some switching occurred before the expected maximum at $H = -H_k$ was reached. A constant internal field antiparallel to $\vec{M}$ was also noted.

D. Magneto-optics

A guiding principle in optimizing the performance of magneto-optical light switches, using optically lossy magnetic materials, is to use a thin film of the magnetic material placed in an optical standing wave at a position where selected components of the optical $\vec{E}$ are zero. The components of $\vec{E}$ can be classified as magneto-optically active ($\perp$ to the magnetization $\vec{M}$) or inactive ($\parallel$ to $\vec{M}$). It is always advantageous to make any inactive component of $\vec{E} = 0$, and this has formed the basis of previous proposals for improving the longitudinal reflection magneto-optical effect.[7] It can be further conjectured that only the incident polarization mode need have a nonzero active component of $\vec{E}$, since only one-way mode conversion is required. This conjecture is not borne out by detailed calculation of the reflection effect; however, the conjecture is true in transmission and, for the incident mode having $\vec{E} \parallel$ to the plane of incidence, results in a maximum theoretical conversion efficiency depending on magnetic film thickness d at least as $1/d^3$ and perhaps to a higher power of $1/d$. The significance of this result lies in the numerical prediction that, for a film of Fe 50 Å thick, the maximum conversion efficiency can approach unity, at which point the theory must be modified to include neglected effects.

III. ADVANCED CIRCUITS

A. Film Memory Sense Amplifier

A strobe/clamp circuit has been added to the output of the four-stage sense amplifier for the magnetic-film high-density memory, and allows faster memory operation. This circuit eliminates base-line shift due to poor digit recovery.

REFERENCES

1. K.J. Harte, "Spin-Wave Effects in the Magnetization Reversal of a Thin Ferromagnetic Film," Technical Report 364, Lincoln Laboratory, M.I.T. (27 August 1964), DDC 610068.
2. J.B. Comly and T. Penney, "Spin-Wave Instabilities in Permalloy Films of Varying Thickness," Scientific Report No. 8, Cruft Laboratory, Harvard University (17 December 1963).
3. E.J. Torok, R.A. White, A.J. Hunt and H.N. Oredson, J. Appl. Phys. 33, 3037 (1962).
4. D.O. Smith, Appl. Phys. Letters 2, 191 (1963).
5. E. Feldtkeller, Proc. Intl. Conf. on Magnetism, Nottingham, England, 1964, p. 837.
6. E.J. Torok, et al., J. Appl. Phys. 35, 3469 (1964).
7. D.O. Smith, Optica Acta 12, 193 (April 1965).

PSYCHOLOGY
GROUP 25

I. MAN-COMPUTER INTERACTION

Work is still concentrated on APEX, the executive system that will share the TX-2 computer among several on-line users. At the time of the previous Quarterly Technical Summary report (15 May 1965, DDC 619676) there was a primitive version, composed mainly of substitutes for the routines that would appear in a more permanent system. One by one the substitutes have been replaced by more sophisticated routines that had been tested in isolation. This was a crucial step. Combining large programs written by different people is always difficult, and the new version provided the first good opportunity to exercise some of the computer changes that had been installed for its benefit.

Progress has been good. Although some features will be missing, APEX may be ready for everyday use in August 1965. An increasing amount of work has therefore been done on the library of routines that will exploit it.

A. APEX

The parts of the system that allocate core and drum storage are operating satisfactorily. They assign registers in real core and in Page Address Memory, and they control the location and bounding registers. They can now handle synonyms for names of files, they can share among two or more users a single copy of a library routine that does not modify itself, and they can keep track, to any depth, of the Map (the arrangement of files) to which the user wants to return when his current program has finished. Files are still limited to 8192 words apiece, and their lengths cannot be changed once they have been defined. The rule for retrieving core storage is still rudimentary.

The primitive system was able to handle the keyboards and printers on more than one Lincoln Writer. The paper-tape reader has now been incorporated into the system, and work continues on the routines for other input and output devices: the Xerox printer, the paper-tape punch, the CRT displays, and the magnetic tape. Work has begun on the complicated programs that will handle Ghost Maps. They will be a way of keeping the user's program ready to respond to an input device (e.g., the light pen) even when it is not his turn to run.

B. Utility Routines

The service routines listed in the 15 May 1965 report are being improved and transferred to the new system. A routine that allows the user to print one of his files on the Xerox is in progress, and a routine that lists the names defined in his Directory is almost ready.

C. Matrix Package

Group 25 plans to conduct research on the human factors of interaction between scientists and computers. Matrix arithmetic was chosen as the field in which to begin, and preparation of a library of matrix routines has been started.

The routines for simple computations and the majority of the routines for noncomputational manipulations (for example, deleting a row) are already checked out. Two routines that perform more difficult computations are being debugged. One of them extracts the characteristic roots and vectors of a symmetric matrix; the other finds the inverse and determinant of a square matrix, or solves a system of linear equations.

Facilities for entering matrices into the system and for printing them are in various stages of planning and coding. Plans are also being made for a routine that will display on the CRT as many as three curves, each showing the components of one vector plotted against the corresponding components of another.

The user will often come to the computer with data that must be transformed before matrix operations can be applied. A rudimentary language that will allow him to describe operations on n-dimensional arrays, somewhat in the manner of Fortran, has been tentatively specified, and a small compiler for the language is now being developed.

II. HUMAN INFORMATION PROCESSING*

A. Recognitive Behavior

Two analyses have been made of Shipley's data on the detection of single and multiple properties of pure tones heard in noise.† One analysis employed Luce's Choice Theorem,‡ and the other employed Thurstone's Law of Categorical Judgment.§ Luce's approach implied that the properties of the stimuli interact in perception; Thurstone's did not. This suggests that Luce's fundamental concept of gross similarity of patterns provides a less realistic approach to the analysis of recognition.

B. Discrimination of Recency

Two previous quarterly reports [15 February (DDC 612541) and 15 May 1965] described experiments on the ability to discriminate which of two pictures had been seen more recently. In those experiments, the pictures had been seen once, at most, during the session. Are judgments of recency altered when one picture has appeared more frequently than the other?

An experiment was conducted in which one of the pictures was sometimes presented twice. For the most part, repeating a picture has the effect of increasing its apparent recency. This finding is consistent with the supposition that the subject judges recency by assessing the clarity of a memory trace.

Another experiment is needed. It appears that the effect of repetition is not a monotonic function of the distance between the two presentations; the present experiment does not reveal the shape of the function in any detail.

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* One of the investigators was a National Institutes of Health postdoctoral fellow.

† E. Shipley, J. Math. Psychol. (in press).

‡ R. D. Luce in Handbook of Mathematical Psychology, R. D. Luce, R. R. Bush and E. Galanter, editors (Wiley, New York, 1963), Ch. 3.

§ W. S. Torgerson, Theory and Methods of Scaling (Wiley, New York, 1960), Ch. 10.

C. Keeping Track of Several Things at Once

Intuitively, it seems that a person who must keep track of the present states of several variables will perform better if the variables have a normal state in which they are usually found. Variables in the normal state should not put a heavy load on his memory; he does not need to keep track of anything but the exceptions (i.e., the variables in abnormal states).

An experiment was performed in which the subject was to keep track of six variables whose states were letters of the alphabet.* In one condition there was a normal state, which was the same for all variables; on the average, only one variable at a time was abnormal. In the other condition, the subject was told that any letter might appear as the state of any variable at any time.

In the condition in which there was a normal state, the subject presumably tended to guess the normal state when he did not remember the correct answer. Even after correction for such guessing, performance was much better in that condition. Thus, a tendency for the variables to be in a normal state is one kind of regularity that a person can exploit in performing the task.

*For a description of the general procedure, see D. B. Yntema, Human Factors 5, 7 (1963).

CONTROL RESEARCH
GROUP 28

I. HYBRID COMPUTER SYSTEMS

The magnetic core memory for the digital differential analyzer has been delivered, and installation of the unit has been accomplished. The entire system is now being checked out.

Programming of a compiler for automatic mapping and scaling of the DDA has been completed and a few test problems have been solved. Some modifications to the scaling algorithm are being made to make problem solving simpler for the user by including automatic rescaling during problem run.

II. ESTIMATION AND CONTROL

Studies on recursive techniques for nonlinear regression are nearly complete. Several papers on waveform design and on the application of stationary processes have been prepared and studies are continuing.

Earlier work on radar accuracy and resolution has been published* along with material on stationary occurrence processes.†

*F. C. Schweppe, "On the Accuracy and Resolution of Radar Signals," accepted for publication, IEEE Trans. Aerospace Navig. Electron.

†O. A. Z. Leneman, "Random Sampling of Random Processes: Step-Wise Processes," accepted for presentation at the Third IFAC Meeting, London, 20 June 1966.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This report summarizes the research and development efforts of Division 3 for the period 1 May through 31 July 1965. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to ARPA.

S.H. Dodd
Head, Division 3

M.A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1965

PUBLISHED REPORTS

Technical Report

TR No.				DDC and Hayden Nos.
389	Millimeter Wave Research: Past, Present, and Future	J.W. Meyer	17 May 1965	DDC*

Technical Note

TN No.				
1965-35	Program Description – Radar Observations of the Planets	J.W. Meyer	9 July 1965	DDC 619708 H-667

Journal Article†

JA No.			
2512	Midlatitude Ionospheric Temperatures on Magnetically Quiet and Disturbed Days	J.V. Evans	J. Geophys. Res. 70, 2726 (1965)

* * * * *

UNPUBLISHED REPORTS

Journal Article

JA No.			
2569	Cause of the Midlatitude Winter Night Increase in f_0F_2	J.V. Evans	Accepted by J. Geophys. Res.

Meeting Speeches‡

MS No.			
1369	The Effect of Roughness on the Polarization of Thermal Emission from a Surface	T. Hagfors J.E. Morriello	Symposium on Planetary Atmospheres and Surfaces, Dorado, Puerto Rico, 24-28 May 1965
1391	Radio Astronomy at Haystack	M.L. Meeks	Physics Seminar, M.I.T., 10 May 1965

* Not yet assigned.

† Reprints available.

‡ Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Unpublished Meeting Speeches (Continued)

MS No.			
1407, 1407A	The Haystack Microwave Research Facility	J. S. Arthur	IEEE Annual Meeting, Rockland, Maine, 10 June 1965; Diebold Group (Data Processing), Hanscom Field, 30 July 1965
1417	A Preview of Radio Astronomy at Haystack	M. L. Meeks	Colloquium, Aerospace Corporation, Los Angeles, 2 June 1965

SURVEILLANCE TECHNIQUES
GROUP 31

Group 31 operates, maintains and conducts research programs with the Millstone radar complex and the Haystack Research Facility of the Laboratory's Millstone Hill Field Station. Research efforts include satellite observation techniques and studies of the ionosphere, including auroras. Significant programs in radio and radar astronomy are also in progress at both Millstone and Haystack.

Of particular interest this period are the results of the polarimetric radar observations of the moon at Millstone. They have provided a basis for a theory explaining for the first time past differences in the dielectric constant of the lunar surface as inferred from (a) radiometric and (b) radar data.

I. SPACE SURVEILLANCE

A. Observational Program

The one-day-per-week satellite observation program continues at the Millstone radar. Operations in support of the MITRE-Millstone interferometer take place evenings at regular intervals. Data on 79 tracks involving 36 objects in the "difficult" class were passed to Space Track.

The Lincoln Space Communications Program received Millstone data on a number of passes of its new 1 square meter Lincoln Calibration Sphere. Several horizon-to-horizon tracks of the sphere served to provide real-time evaluation of pointing instructions computed at Haystack for pointing both Haystack and West Ford at artificial satellite objects. In the pointing evaluation experiment, Object No. 192 was also utilized. During these tests, Haystack operated in a non-tracking mode and obtained X-band echoes from these objects (prf = 10 to 20; P_T = 25 to 40 kw; τ = 10 msec). (These were the first satellite observations with Haystack.) It appears that, in the satellite mode, the Haystack pointing computer can, on a well-known orbit, point Haystack to well within the X-band beamwidth.

Another tracking landmark at Millstone was achieved on 13 May 1965 when LES-2 ($\sigma \approx 0.2\,m^2$) was acquired beyond 4000 nm and tracked to beyond 5000 nm. For this operation, the pulse width was doubled (20,000 joulepulse) and unneeded sections of the doppler filter bank were removed in order to obtain increased sensitivity.

At the request of Government agencies, target characteristics were measured on two special satellites. One required tracking at long range during two passes; the other required equipment modifications to adapt the Millstone system for obtaining scintillation data at a prf of 100 pulses per second.

Two Trailblazer operations were observed. On 4 May 1965, the wrong stage was acquired resulting in loss of re-entry data. The 26 June operation was successful and all data were given to Group 21 (Surveillance) for analysis.

A Journeyman rocket from Wallops Island was tracked at the request of NASA. On the basis of misinformation from Wallops concerning the actual course taken by the vehicle at liftoff,

Millstone broke track after observing for $3\frac{1}{2}$ minutes what later proved the correct object, in order to search the nominal trajectory fruitlessly.

Extra operations with MITRE were conducted (1) for a series of "PRELORT" calibrations of Millstone, the interferometer and other SPADATS sensors, and (2) for comparison of observations with those made by the multistatic radar of Cornell Aeronautical Laboratories.

B. Sensor Improvement Program

This modest program aims first at improving the satellite-observing capability of Millstone itself, and second at developing and testing techniques for use in improving the capability of any tracker.

Phaseout of the local SCAF (Spacetrack Center Alternate Facility) at Hanscom has added impetus to the drive to obtain computer programs that will permit handling orbital computations directly at Millstone. TRW Systems Group (STL) has been awarded a contract to provide such programs based upon their ESPOD system.

Tests of most parts of the digital monopulse system have been successful; 4-Mcps operation of the A/D converters is vital, however, and has not been achieved. The entire system may have to be reconsidered unless this problem is solved soon.

A longer-range goal is the use of planetary signal processing techniques to increase the satellite-observing range. Both an accurate real-time ephemeris program and a high-speed spectral processing capability are required. The latter requirement is being approached using techniques developed at Lincoln and IBM.*

II. RADIOMETRY

During the 64 days for which the Radiometer Box was on the Haystack antenna, 412 hours were used for measurements divided between two objectives: (a) continuing evaluation and calibration of the antenna, and (b) observations of various sources and of the effect of precipitation.

A. Antenna Evaluation (Haystack)

Calibration of antenna pointing to ±0.008° (adequate for X-band work) was completed last period. The next step, to calibrate pointing to ±0.003° and to prepare correction tables for entry into the computer program, is well under way. Extensive position measurements were continued and data are now nearly adequate to complete this step.

In general, pointing performance under computer control has been steadily improved and is now quite satisfactory for 8- and 15.5-Gcps observations.

To facilitate continual recheck of pointing performance, the so-called Discrete Source Scanning (DSS) program was written for the pointing computer and has proved very useful. This program automatically scans the antenna in right ascension and declination about the position of a source, calculates the position of peak response, the widths to half-maximum and measures the peak antenna temperature. Results are printed out immediately.

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* J. W. Conley and J. W. Tukey, Math. Comput. 19, 297 (1964).

Antenna efficiencies near* 46 percent were measured at 7.75 Gcps using the multimode horn feed in the radar/communications (R/C) box. Since this compared with ≈32 percent for the Clavin feed, a simple horn was constructed for use at 15.5 Gcps. With this horn, measurements on 3C273 indicated a 23-percent efficiency as compared to the 15 percent measured with the Clavin feed.

B. Observations

Measurements at 8 Gcps of polarization of thermal emission from the moon were made in connection with the development of theories of the lunar surface.

Maps were made for the bright radio sources Cassiopeia A and Taurus A at 15.5 Gcps. The structure thus revealed will make possible more accurate measurement of the antenna gain when compared with measurements with the standard gain horn.

A number of planetary nebulae have been observed at 8 and 15.5 Gcps, and a lunar occultation of 3C273 was observed at 8 Gcps.

Studies of emission from precipitation now in progress are required since bad weather seriously compromises radiometric measurements at these frequencies.

C. Solar Studies

The Haystack antenna facility was utilized several days in the late spring of 1965 (18 and 26 May, 9 and 14 June) for surveys of the radio emission from the sun at 8 and 15.5 Gcps. These initial solar observations were undertaken primarily to determine the most effective scanning procedures for exploiting the high angular resolution and tracking capabilities of this system in the mapping of the emission from the solar disk and, hopefully, for future applications to a study of spatial and temporal characteristics of regions of enhanced emission associated with solar activity.

Further reduction and analysis of the solar radiometric data obtained in these observations are continuing in order to construct contour maps of solar brightness temperature with appropriate calibration factors and to evaluate experimental techniques. As a result of experience gained in these experiments, it is believed that further modification of some aspects of the scanning program and automation of the data reduction will be required in order to establish a regular schedule of solar observations.

III. RADAR ASTRONOMY

A. Lunar Studies

Work has continued both at Millstone radar and at Haystack in instrumenting for more detailed studies of the lunar surface.

Until recently, there has been unexplained disagreement between the values of dielectric constant inferred from radar measurements and from radiometric measurements. Including the

* All efficiencies referred to the output flange of the feeds. If radome loss is not considered, an antenna efficiency at 7.75 Gcps of nearly 60 percent is being achieved.

effect of surface roughness in the theory* reduced, but did not resolve, the disagreement (see Quarterly Technical Summary for 15 May 1965, Sec. II-B, p. 26).

Results of a new polarimetric radar experiment† performed at L-band with the Millstone radar have suggested a multilayer model of the lunar surface having an extremely tenuous surface layer at least one wavelength deep, underlain by a somewhat irregular structure of denser nature. This model can explain past deductions of $\epsilon \approx 1.6$ to 1.8 from radiometric data, and $\epsilon \approx 2.6$ from radar data.

The newly achieved polarization flexibility at Millstone was used, together with the well-known range-doppler surface mapping techniques, to show a systematically different back-scattering strength at oblique incidence for waves polarized in the plane of incidence as compared to waves polarized orthogonal to it. Such an effect may be predicted from the difference in the transmission coefficients for two such waves in penetrating a tenuous top layer. It was further observed that no such effect was present in the region of Tycho, where previous observations have suggested a surface approaching bare rock.

The variable polarization system at Millstone has required a great deal of effort in order to yield accurate, reliable measurements at high power. The results to date show great promise, however, for planetary as well as lunar studies, and decisions concerning RF feed configurations to be provided in the future for Haystack have already been influenced.

B. Planetary Studies

The data obtained from the CW radar observation of Mercury in April 1965 have been fully analyzed, including reprocessing of the analog tape recordings in a bandwidth wider than that used during the real-time experiment. Analysis confirms the initial result of 5 percent cross section (±3 db), but shows a spectral bandwidth of about 75 cps instead of the 65 cps reported initially.

If progress on R/C box improvements permits, a similar CW experiment will be performed in August with perhaps an 8-db increase in over-all radar sensitivity. Transmission would be at 100-kw level and helium cooling of the parametric amplifier would be utilized. Arrangements for direct control of the doppler offset by the computer are in progress. Mercury ephemerides are being prepared for the required times.

Plans are under way to observe Venus at the Millstone radar beginning in October. Accurate ranges will be determined on a portion of the orbit not previously observed.

IV. ATMOSPHERIC STUDIES

A. Observations

Ionospheric backscatter observations at 400 and 1295 Mcps have continued at 48- and 12-hour periods once per month, respectively. Observations are made when possible on the IQSY Quarterly World Days and Regular World Days.

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*T. Hagfors and J. E. Morriello, "The Effect of Roughness on the Polarization of Thermal Emission from a Surface," presented at Symposium on Planetary Atmospheres and Surfaces, Dorado, Puerto Rico, 24-28 May 1965.

†T. Hagfors, et al., "Evidence of a Tenuous Surface Layer on the Moon as Derived from Radar Observations," submitted to Science.

A substantial amount of thought has gone into the design of system revisions that will permit reduction of the data and spectral determinations in much less time than at present. Since the ionospheric program is planned to continue with increased emphasis as solar activity increases, the reduction in processing time and the effort afforded by such revisions would be most worthwhile.

In an exploratory test, the West Ford 60-ft antenna was used in an attempt to observe atmospheric backscatter from 1.5-μsec pulses transmitted from Haystack at 25-kw peak power. In scanning the West Ford antenna up and down the Haystack beam, apparent echoes were detected at an altitude of 5000 ft. Explorations will continue as Haystack performance is increased.

L-band auroral observations scheduled one to two days per week have yielded data on some 40 percent of such days. Preliminary analysis shows echoes over an azimuth sector of 60° centered on the magnetic meridian, with a maximum elevation angle usually less than 6°. The observed effective cross section is on the order of one square meter and the width of the doppler spectrum is about 12 kcps. Computer programs for use in analysis of the data are being written.

V. SPACE COMMUNICATIONS

A highly successful full-duplex teletype communication demonstration was conducted between Haystack and Camp Parks via the moon. The Group 62 "White Truck" was coupled to the Haystack equipment to supply modulation and demodulation facilities. Both stations used a transmitting power of 5 kw.

VI. EQUIPMENT HIGHLIGHTS

An engineer has been assigned the task of overseeing the development of the new high-power planetary radar for Haystack, to be used in the long-range planetary measurements required for the so-called Fourth Test of General Relativity.* Initial large procurements have already been made, including the tubes and box structures.

The Series Beam Switch Regulator provided on loan by RADC has permitted pulsed operation of a 25-kw klystron at Haystack for the first time.

The work of bringing the R/C box transmitter up to a reliable 100-kw level is well advanced.

Some 550 hours of operating time were scheduled and manned on the Haystack antenna. Pointing performance to ±0.005° has been achieved with good regularity on sidereal rate targets.

Improvements to the timing system, doppler tracking and digital-data-processing equipment have entailed substantial work at Haystack. Design of the interfaces for a newly ordered commercial computer to be used for processing in future radar applications has also begun.

At Millstone, a group of engineers has considered re-engineering the system to isolate the equipments used in tracking and in ionospheric studies from those used in other experiments in order to simplify operations and reduce demands upon experienced personnel.

The commercial computer at Millstone (delivered last November) has still not been accepted, though a promising period of acceptable performance began near the end of this quarter.

Perhaps the most significant improvement at Millstone has been the realization of the polarimetric capability mentioned in Sec. III-A.

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*I. I. Shapiro, Phys. Rev. Letters 13, 789 (1964), DDC 613894.

RADAR
DIVISION 4

INTRODUCTION

This report summarizes the General Research activities of Division 4 during the period 1 May through 31 July 1965. The major portion of Division 4's activities is devoted to PRESS, Radar Discrimination Technology, BMRS and Space Communications, which are described in separate reports. The General Research activities in Division 4 involve Groups 42 and 46 on Haystack Instrumentation, Group 44 on Phased Arrays, and Group 45 on Millimeter Waves.

This is the last quarterly period in which Phased Array activities will be reported under General Research; beginning 1 July 1965, this research will be sponsored by ARPA as part of the Radar Discrimination Technology Program.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

DIVISION 4 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1965

PUBLISHED REPORTS

Technical Report

TR No.				DDC and Hayden Nos.
380	AC Breakdown in Gases	C.E. Muehe	26 February 1965	DDC 618503

Technical Note

TN No.				
1965-33	Fringing Capacitances for Offset Coupled Strips in Shielded Strip Line	W.J. Getsinger	1 July 1965	DDC 618927 H-660

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
2572	Magnetostriction Effects in Remanence Phase Shifters	D.H. Temme E. Stern	Accepted by IEEE Trans. Microwave Theory Tech.
General	Review of Radar System Analysis, by D. Barton (Prentice-Hall, New York)	H.G. Weiss	Accepted by J. Franklin Inst.

Meeting Speeches*

MS No.			
1227	Definitions for Diode-Package Circuit Elements	W.J. Getsinger	International Solid State Circuits Conference, Philadelphia, 17-19 February 1965

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

RADAR SIGNAL PROCESSING
GROUP 42

I. INTRODUCTION

Group 42 presently is engaged in supporting three Laboratory projects: PRESS, Radar Discrimination Technology and Haystack.

The PRESS and Radar Discrimination Technology activities are described in Semiannual Technical Summary Reports to ARPA. A description of the work on Haystack Instrumentation is given here.

II. HAYSTACK INSTRUMENTATION

All Haystack equipment for which Group 42 has been responsible has been completed and is operating on site. The list of equipment includes: (a) sequential doppler processor; (b) monopulse angle estimator; (c) test signal generator and target simulator; (d) antenna position digital control subsystem; (e) digital range tracker; (f) real-time clock; and (g) computer interface buffers for angle, range, doppler and time.

The remaining work comprises: site-personnel technical indoctrination, and testing of the interfaces between the monopulse estimator and the remainder of the angle-tracking equipment. Under investigation is a condition of insufficient dynamic range in the monopulse angle estimator.

ARRAY RADARS
GROUP 44

I. INTRODUCTION

The material presented here concludes the progress reporting of Group 44 within the General Research Phased Array Program. Beginning 1 July 1965, our activities in phased array technology and the ADAR program will be documented in the Semiannual Technical Summary Reports to ARPA. This change reflects the shift of our program sponsorship from General Research to ARPA within the Radar Discrimination Technology Program.

II. FERRITE COMPONENTS

A. Phasers

Initial peak-power tests of the helical phaser indicated an RF breakdown near 20 kw. Although this is considered adequate, some effort may be spent to reduce a high field point at the matching entrance to the helix.

B. Switching Circulators for Time Delays

A switching circulator with a stripline 3-port Y-junction has been designed with its ferrite element operating on a minor hysteresis loop. An external composite circuit is provided for switching and holding one of two circulation states. The results to date are:

	S-Band		X-Band
	Calculated	Experimental	Calculated
Bandwidth for 26 isolation (Mcps)	400	150	100
Insertion loss (db)	0.2	0.35	0.2
Switching time (μsec)	<5	<5	<5
Switching energy (μjoules)			
(1) Hysteresis loss	170	180	20
(2) Eddy-current loss	—	450	—
Temperature stability (phase/°C)	1°/10	1°/10	1°/20
RF peak-power capability (kw)	>15	>15	>10

C. High-Power Phasers

An analysis of the waveguide nonreciprocal remanence phasers has been completed. Utilizing the results of this analysis, a 100-kw S-band phaser is being designed and constructed. A paper summarizing this analysis will be presented at the 1965 International Conference on Ferrimagnetics, London, England, 13–17 September 1965.

D. Ring Circulator

A small compact comb filter nonreciprocal phase shifter has been developed for use in the ring circulator. It has up to 35° nonreciprocal phase shift, flat within 10 percent over a 500-Mcps band centered at 2.75 Gcps.

Bandwidth of the circulator vs differential phase for various simple reactive matching arrangements has been studied. In the configurations studies, the bandwidth tends to be narrow (6 percent or less at 25-db isolation). Calculations now in progress show how improved matching techniques can be used to achieve appreciably larger bandwidth. Experimental investigations are being performed on a model of the circulator in conjunction with the theoretical analysis.

III. ANTENNA ELEMENT MUTUAL COUPLING

Computer programs have been written to compute the impedance and gain properties of simple array elements in a regular, infinite array environment, as opposed to the finite array problems previously studied. These studies are presently restricted to elements which can support only a single mode, e.g., thin dipoles with a sinusoidal current distribution. The multimode problem (an infinite array of open waveguides, for example) will be pursued in the coming months. Formulas for infinite arrays of crossed-dipole-pairs have been derived, but as yet no detailed numerical results have been obtained.

Some preliminary investigations of edge effects in large, linearly polarized arrays have been conducted using approximate techniques. These studies will be continued and will later be extended to include the problem of edge effects in large arrays of crossed-dipole-pairs.

The support structure for the dipole, waveguide and log-periodic planar arrays has been completed. An L-band pattern range has been constructed and is being checked out. Initial measurements indicate that there is some spurious scattering which needs to be reduced.

The first mutual impedance measurements of the log-periodic array have been obtained. These results are presently being analyzed to clarify the unusual behavior of the impedance plots.

The open-ended waveguide array is nearly complete.

IV. SOLID-STATE TRANSMITTERS FOR VHF-UHF ARRAYS

As a result of preliminary studies, the following specifications have been selected as the objectives for a multistage, pulsed-transistor power amplifier.

Frequency	200 Mcps
Bandwidth	5-percent minimum
Gain	10 db
Power output	1 kw

Choice of these characteristics is predicated primarily on the utilization of presently available multi-chip overlay transistors. Parallel investigations of transistor-combining techniques (parallel, series parallel, etc.) and pulse ratings (thermal constant and voltage breakdown) are under way. Results from these investigations will be combined in a design of a prototype amplifier.

The VHF-UHF power amplifier is also being considered from a semi-integrated circuits viewpoint; that is, the transistor chip would be directly incorporated in coaxial or a thick strip circuit (toward the elimination of the effect of the transistor package). It is anticipated that this is the ultimate direction of the solid-state transmitter program; however, for the present it will remain a study effort only.

RANGE MEASUREMENTS
GROUP 45

Work in the millimeter-wavelength project has centered in the areas of receiving equipment improvements and source observations during this reporting period. Conversion of the receiving equipment to a polarization sensitive mode was completed. This conversion required completion of the following work: (1) a directional coupler in circular waveguide was designed, constructed and tested; (2) a driver for the ferrite polarization switch was constructed and calibrated; and (3) the microwave portion of the radiometer was changed to accommodate the new components. This latter change was made on a temporary basis, awaiting the fabrication of some new waveguide pieces.

When the radiometer was ready, observations were begun on the sun and the moon. In the sun's radiation, no polarization was observed which could not be attributed to instrumental effects, chiefly to the effect of the feed. Although the instrumental effects observed are not yet fully understood, they were less than 1 percent after systematic effects were removed.

For the moon, the polarization observed was about 6 percent. This effect is due chiefly to the dielectric discontinuity at the lunar surface. A series of measurements have been undertaken which will allow us to study this effect and to measure the lunar temperature variations over a lunation. Analysis of these data has required extensive modification of existing computer programs.

A study of atmospheric attenuation at a number of frequencies was initiated during this reporting period. We used the technique of observing the sun as it sets in order to determine the dependence of signal strength with elevation angle. From measurements at low elevation angles, the zenith attenuation (opacity) can be determined accurately. The measurements being made by Lincoln personnel at 8.6-mm wavelength are intended to provide an empirical calibration for another, more convenient method of measuring the same quantity. Measurements being performed by M.I.T. personnel and students at a number of wavelengths near the water-vapor absorption line are intended to detect the presence of water vapor at high altitudes. Their measurements yield the shape of the absorption line, which admits to identification of the water-vapor height.

The 8.6-mm wavelength radiometer being constructed for use on the Haystack Research Facility was completed during the reporting period and is currently being tested. This receiver is similar to that in use in the 28-ft antenna, and will be available to check the gain of the Haystack antenna at 8.6 mm when this seems warranted.

A thorough analysis of the data taken during the 19 December 1964 lunar eclipse has been undertaken, although results are not yet available.

During this reporting period, the following sources were observed: the Sun, the Moon, 3C273, 3C84, 3C279, the Orion Nebula, and the Galactic Center. Results of these observations are discussed in other reports.

MICROWAVE COMPONENTS
GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave requirements arising from radar projects. Contributions are made to the General Research Program through the support of Haystack Hill, operation of a high-power microwave laboratory, development of low-noise receiver techniques and receivers for space communications, and studies of very-high-gain antennas and antenna feeds.

II. HAYSTACK HILL MICROWAVE COMPONENTS

A. Noise-Rejection Filter

Both low- and high-power tests have been completed on the six-cavity-pair, 8350-Mcps, noise-reject filter. Over the pass band from 7742.5 to 7762.5 Mcps, the VSWR was less than 1.03 and the insertion loss was 0.05 db or less. Over the stop band from 8325 to 8370 Mcps, the rejection was greater than 80 db. The filter carried 305-kw CW in the pass band around 7750 Mcps without voltage breakdown or excessive heating.

Technical Note 1965-30 describes this filter.*

B. Low-Noise Receivers

Four canned parametric amplifier assemblies have been fabricated for use at the Haystack site. Two of the assemblies have been operated at both liquid nitrogen and liquid helium temperatures. At 4.2°K, the units exhibited receiver noise temperatures of less than 50°K at a frequency of 7750 Mcps. The best receiver temperature measured was 36.5°K at 8050 Mcps. A third parametric amplifier assembly has been tested at only 77.4°K. RF tests at cryogenic temperatures have not been made of the fourth unit.

C. Transmitter Completion and Simplification

The transmitter conversion to a 25-kw, VA-849 for low-power usage has been completed and successful operation obtained in CW, pulsed and dual-frequency communication modes. Control and monitor circuits were simplified by site personnel, and waveguide components were redesigned by Group 46 to facilitate changeover of tubes and be more compatible with the final choice of operating procedures and the Electro Scientific Industries, Inc. control console. Further weight and space reductions were also effected.

The high-power harmonic filter, noise-rejection filter, and 8350-Mcps bandpass filter were installed and proved satisfactory. Waveguide sections were made to facilitate reconfiguration of

* W. J. Getsinger, "A Noise Rejection Filter for Waveguide Carrying High Power," Technical Note 1965-30, Lincoln Laboratory, M.I.T. (3 August 1965), DDC 619580, H-666.

transmitter and receiver from this communication mode to the single frequency CW or pulse mode with minimum-loss receiver paths. The change now takes only a few hours, so both types of usage were available in the same day.

The final version of the VA-879 rack with a new water-cooling manifold will be complete the week of 2 August 1965. The microwave power-monitoring section of this rack is complete in the new compact configuration. The latter provides for two thermistor mounts (of either waveguide or coaxial design) and two crystal detectors, each with its individual level set attenuator, in one compact, well-shielded unit. It provides for monitoring and logging forward power, feeding forward-power signals to the VSWR monitor, and providing video signals for pulse envelope viewing. One thermistor mount and two crystals form a second package for reverse-power monitoring. In addition, two harmonic filters, terminations, pressure windows and high-power directional couplers are now located in the transmitter tube cabinet on easily detached brackets where it is necessary to allow for klystron removal.

D. Multimode Feed

The complete antenna has been tested with the R/C high-power box in place. It has been determined that the antenna gain is 66 ± 0.5 db over isotropic at 7.75 Gcps. Allowing 1.2 db for radome losses and 0.8 db for reflector tolerance, it appears that with no radome and a perfect reflector an aperture efficiency of 71.8 ± 8 percent has been realized with this multimode feed, Cassegrainian reflector system. This implies that the beam efficiency of the feed must be at least 90 percent. A four-horn cluster used as a tracking feed would have provided a secondary aperture efficiency not greater than 50 percent since its beam efficiency is not higher than 65 percent. The secondary aperture efficiency achieved with the multimode horn exceeds that obtainable with a simple one-mode horn of low phase error having the same beamwidth in both principal planes. The noise temperature of the antenna using the R/C box is exceptionally low. It is known to be lower than that obtained with nontracking, low-power feeds in the same antenna by 20° to 30°K.

Gain and noise temperature results have been obtained radiometrically, but pattern measurements have been made using a transmitter on Pack Monadnock Mountain at $1.19D^2/\lambda$ from the Haystack site. These patterns show the expected beamwidths and side-lobe levels in azimuth cuts. The total 3-db beamwidth is 0.068° ± 0.003°, and the total 10-db beamwidth is 0.116° ± 0.003°. The first and second side lobes are approximately 24 and 28 db, respectively, below the peak of the main lobe.

It was determined that the level of on-axis, cross-polarized energy was about 40 db below the peak of the normally polarized energy, and that the peak cross-polarized level was 22 to 24 db below the peak of the main lobe.

A new version of the multimode feed, to work in the band 7840 ± 100 Mcps and at power levels of up to 500-kw CW, has been developed. This is intended for the "planetary radar" box. The input VSWR and the axial ratio of the feed will be 1.1:1 or better over this band. Gain and noise temperature results are expected to be similar to those obtained with the R/C box.

High-power tests of the feed components and of mylar pressure windows are planned.

III. SOLID-STATE AMPLIFIERS

A. Wide-Band, Low-Noise X-Band Parametric Amplifier

An X-band parametric amplifier has been designed on the basis of the concepts and techniques developed in Group 46 over the past few years. The major parts of the parametric amplifier are under construction, and the pump tube and diodes have been ordered. Although emphasis in design was placed on achieving the widest bandwidth, which is expected to be on the order of 600 Mcps, the noise performance of the amplifier is also expected to be appreciably better than that of present state-of-the-art X-band parametric amplifiers.

B. Diode Measurements

A number of experimental GaAs varactor diodes have been supplied by Micro-Optics and evaluated at cryogenic temperatures with good results.

A log is being kept of all the diodes purchased for projects which require parametric amplifiers. Both cryogenic and DC performance are included in this log.

IV. NEW TR TUBE FOR MILLSTONE HILL UHF RADAR

A new TR tube has been designed, built and tested for the UHF backscatter radar at Millstone Hill. The tube previously used was a metal-electrode tube filled with argon and water vapor which, during a system noise test, exhibited an added noise contribution for several milliseconds after the end of the transmitted pulse.

The new tube is a folded-cylinder TR tube of approximately 1-in. diameter with a 2-mm gap. It is filled with helium at about 4 torrs. Aluminum electrodes are cemented to the outside of the tube which is designed to fit in a tunable cavity. This cavity is placed ahead of the cavity containing the old metal-electrode TR tube (which is still required since the leakage from the new tube is quite high). Both cavities are installed in series in the orthogonal line of the UHF radar where the input power is about 50-kw peak and the pulse length is as long as 2 msec.

In a conventional recovery-time measurement, where the insertion loss is measured in the recovery period, the TR recovered within 100 μsec. During a system noise test, excess noise existed for a period of 350 μsec following the transmitted pulse. It is not clear whether or not this noise came from the TR, since the cable to the TR could be disconnected and noise was still present although smaller in amplitude. Further investigation of this matter is required. The new folded cylinders were made of pyrex and showed about 0.3-db loss. When the design is fully tested, the cylinders will be duplicated in quartz and the loss should be only about 0.05 db.

V. RING CIRCULATOR STUDY

In a recent article,* J. A. Weiss studied the properties of a symmetrical, three-port ring network composed of reciprocal T-junctions and nonreciprocal phase shifters. He showed that many such junctions, when combined with appropriate phase shifters specified by the theory,

* J. A. Weiss, IEEE Trans. Microwave Theory Tech. MTT-13, 38 (1965), DDC 616432.

form perfect circulators. As an extension of his work, we are computing the properties of a ring circulator using simple T-junctions. The ring itself has one characteristic impedance, and the connecting lines have another. The scattering coefficients of the T-junctions are independent of frequency and depend only on the ratio of the two characteristic impedances.

Simple equations have been derived which give the forward and reverse phase shifts required between junctions to yield perfect circulation. A computer program has been written for the calculation of the various output and ring waves when the phase shifts depart by any assigned values from those required for perfect circulation. Also calculated is the reflection coefficient which must be provided in each input and output arm to yield perfect circulation. A graph of this reflection coefficient as a function of forward and reverse phase for a given value of impedance ratio allows a prediction of the broad-band characteristics of the circulator.

Some preliminary results of the calculations follow. The ratio of the ring characteristic impedance to the connecting line characteristic impedance must be between zero and one for perfect circulation. In the lowest mode for all impedance ratios, the forward phase shift all the way around the ring is very nearly 360°. The differential phase shift per section (1/3 ring) varies from 60° for an impedance ratio of one, to 0° for an impedance ratio of zero. Although the required differential phase shift is small for low impedance ratios, the ring waves are built up so high that the insertion loss is actually independent of impedance ratio in this region. Based on a constant ratio of insertion loss to differential phase shift, the insertion loss of the ring circulator should be only slightly lower than that of the differential phase shift circulator. The lowest mode ring circulator seems equivalent to the Y-junction circulator and, in view of the above results, it is difficult to explain why the Y-junction circulator has such low loss at UHF frequencies compared to a differential phase shift circulator. The answer might lie in the fact that the Y-junction circulator generally operates a long way from resonance, which is not true of the differential phase shift circulator. Since the resonance lines are known to be far from Lorentzian in shape, a lower loss may be encountered far from resonance. Further calculations to determine the peak power-handling ability and bandwidth are in progress.

ENGINEERING
DIVISION 7

INTRODUCTION

Participation of the Engineering Division in the General Research Program consists primarily of the design, fabrication and installation of mechanical devices for several research projects. During this quarterly period, the principal effort has been in support of the facilities at both Millstone and Haystack Hills, as well as in further development of computer programs for structural analysis, especially of complex antennas.

J. F. Hutzenlaub
Head, Division 7

MECHANICAL ENGINEERING
GROUP 71

I. MILLSTONE HILL L-BAND ANTENNA SYSTEM

Two precision gear reducers together with flexible coupling flanges are being ordered, in addition to a prior order of two reducers which, when installed, will reduce the drive system backlash and increase antenna pointing accuracies.

Two WR-770 power-divider waveguide sections are being fabricated and tested. These components, replacing existing WR-650 units, will be installed in the transmit and ortho-sum waveguide lines to enable greater power-handling capabilities.

A 10-foot-square nylon safety net is being placed between the torque tube and the turret platform for personnel protection while servicing waveguide in this area.

II. STRUCTURES RESEARCH

Work has continued on paraboloidal shell analysis, the improvement and development of computer programs for the analysis of frames structures, and a basic study dealing with matrix ill-conditioning in the field of structural analysis.

A. Paraboloidal Shell Analysis

The first three chapters of the user's manual for LLAPS (Lincoln Laboratory Analysis of Paraboloidal Shells) have been issued. Work was continued on the next three chapters of this report and on Parts V and VI of Group Report 71G-1, "Distortion and Stresses of Paraboloidal Surface Structures." These sections deal with sandwich shells and thermal distortions, respectively. A design study was begun which deals with the influence of shell behavior on the structural design of large antennas.

B. Framed Structures Analysis

The modifications to the STAIR Program and the expansion of the dynamic analysis program were completed during this quarter. Documentation of this effort is well under way and should be complete during the next quarter.

C. Ill-Conditioned Matrix Study

A study program was begun in the field of ill-conditioned structural matrices. In the past, such matrices have caused serious problems which could be corrected only by considerable effort. An ill-conditioned system magnifies and propagates errors during the process of obtaining the solution via the computer. In order to obtain meaningful solutions to these systems, it is necessary to acquire a greater understanding of error propagation in structural problems and to devise methods that minimize these errors or remove their source. An engineering rather than a mathematical approach is being used because of the particular properties of structural matrices.

D. Radome Optimization

The RADES (RAdome DESign) Program is being developed to aid in the design of future radomes. This program is utilized in conjunction with the STAIR and SLOP Programs, in a continuous loop, until a design is obtained which is considered to be correct. The criterion that is used to judge the correctness of any specific design is the correlation between the assumed member sizes and the designed dimensions. In its present stage of development, the program designs only solid circular cross sections. It is planned to extend this program so that it will be possible to select different types of cross sections. It is also planned to include a selection of different materials for various sections of the structure, the selection of different methods of connection at the hubs, and an attempt to increase the accuracy with which present phases of the design process are accomplished. In this respect, the determination of a valid stability criterion must receive primary consideration.

III. HAYSTACK

A. Planetary Radar Equipment

Preliminary design studies are being made for a Planetary Radar Equipment Box. The basic North American Aviation (NAA) frame is being used with closeouts, and with electrical and water connections similar to the existing two radar boxes.

This system will use two 250-kw klystron tubes which will be housed in a separate roll-out carriage to facilitate tube replacement and handling. Weight and balance studies are being made in order to determine the optimum positioning of additional equipment which includes a maser receiver assembly, three electronic racks, water manifold, feed horn, and interconnecting waveguide.

Preliminary plans also call for a universal antenna-mounted air conditioning unit with flexible connections for all future radar boxes. Ground-level tube handling and test dock facilities are also being considered in the studies.

The operational date proposed for the planetary radar box is early summer 1966.

B. RF Box (Communications)

The redesigned water-cooling manifold has been fabricated and pressure tested. The manifold, along with new flow-limiters and meters, new shutoff valves, and new flexible lead-in lines, is now being installed in the box at the site.

C. Hoist System Modification

The design of the auxiliary hoist system at the rear of the antenna is nearing completion. Most of the catalog hardware has been ordered, including a compact lightweight hoist with several safety features such as fail-safe brakes and an overload slip clutch.

D. Antenna Measurements

In conjunction with antenna calibration efforts, work is continuing on obtaining correlation between previous structural analyses and the actual behavior of the antenna. Previous efforts in this area included model testing and prototype testing, both in NAA's plant and at the field site.

A series of stretch-wire and dial indicator measurements were made during this quarter by Group 76 as a supplement to previous measurements. In this latest series, the relative movement of the following parts of the antenna were measured:

Secondary reflector to RF box

Secondary reflector to inner edge of primary reflector (top)

Vertical diameter change

RF box to inner edge of primary reflector

Secondary reflector to outer edge of primary reflector (bottom)

Secondary reflector to primary reflector at ring 5 (bottom)

Secondary reflector to primary reflector at midpoint between rings 4 and 5 (bottom)

Secondary reflector to primary reflector at ring 5 (top).

The measurement error with these devices is estimated to be ±0.020 inch. The correlation of the calculated and measured deflection showed a peak difference of ±0.040 inch. This correlation is quite good and is further verification of the accuracy of the Haystack structural analysis.

E. Antenna and Radome Thermal Investigation

Phase I of this program has been completed with the following results:

(1) A 15° ambient air temperature difference between the front and back surfaces of the $\frac{1}{2}$-inch aluminum honeycomb panel reflector surface will establish a 1°F temperature difference between the two facing sheets of the honeycomb panel. It has been computed that for a 1°F temperature difference between the two facing sheets, the panel could produce a deflection of as much as 0.060 inch at midspan between any two rings of the reflector backup structure.

(2) The maximum air-temperature difference recorded between the front and back of the reflector panels to date has been about 3°F.

(3) Computations, based upon a 6-percent transmissivity of the radome, indicate that radiant heat from the sun impinging on a panel could cause a temperature drop across the reflector panel of $\frac{1}{2}$°F. The conservatism in the assumptions and calculations, however, leads one to suspect that a temperature drop of 0.1°F is more likely.

(4) Data reduction is under way in the attempt to determine the temperature gradients and air stratification throughout the radome. A cursory look at the data indicates that for 30 to 50 percent of the time, the excursion of the ambient air temperature throughout the radome is within 10°F. In the vicinity of the reflector surface, the excursion of the ambient air temperature has been well within 10°F for all the observed time.

The above data lead to the following conclusions. The present method of heating the radome may result in some local hot spots, but it does not appear that it has established a temperature gradient in the radome that could adversely contribute to a temperature differential across the faces of the reflector panel. Under the worst conditions observed, panel deflection due to the temperature difference of the facing sheets established by the heating system and radiant heat of the sun could cause the panels to deflect between 0.015 and 0.020 inch.

Phase II of this investigation has just been started and will concern itself with studying the distortion of the antenna structural elements which results from the observed ambient air temperature that fluctuates between 65° and 90°F. Analysis of the major components of the antenna structure shows a spread of approximately 50 to 1 in their thermal inertias.

CONSTRUCTION ENGINEERING
GROUP 75

During the last quarter, the Construction Engineering Group's effort at the Haystack-Millstone Hill complex was in the construction of a 40 × 80 ft concrete pad, structural revisions to the test dock, and modifications to the air conditioning system.

CONTROL SYSTEMS
GROUP 76

This quarter's General Research effort consisted of direct support of Haystack site operations, as well as of antenna system measurements and development.

Support of site operations consisted of directing trouble-shooting efforts, initial establishment of procedures and equipment to achieve increased reliability, and development of digital-servo control to a point where the antenna smoothness and positioning performance adequately support site stellar and planetary experiments. Tests have shown design inadequacies in the hydraulic systems for both the servo system and the hydrostatic bearing.

I. DRIVE AND CONTROL SYSTEM

Antenna drive and control system development concerned both hydraulics and electronics. To support this work the following has been undertaken:

Installation of a hydraulic test stand

Modifications ordered for the presently used antenna servo control valves

Two new special developmental servo valves ordered for evaluation

Loan established of a new developmental vane-type servo motor for bench test and evaluation

In-house construction and development of a flow measuring device which will give information on servo-valve resolution and flow control, especially for the extremely low flow rates required by the antenna

Design and fabrication of antenna servo-motor-driven tachometer assemblies for deriving a high-performance tachometer output

Construction of special electronics and purchase of special pressure transducers for deriving hydraulic control system differential pressure signals

Design and start of fabrication of an antenna servo control loop for operation on the hydraulic test stand.

II. REFLECTOR SURFACE DEFLECTIONS

A series of deflection measurements has been made to determine the present condition of the Haystack reflector with respect to deflection of the surface at various elevation angles. The measurements were taken by using a stretched wire technique and making comparative readings for various elevation angles by recording on a strip recorder.

The lack of easy access seriously limited the number of places on the reflector that could be measured. In general, the results agree with predicted results made by the FRAN Program, and it is felt that the measurements confirm the suitability of the FRAN Program for deflection predictions to be used in the re-rigging study and possible re-rigging of the reflector.

SOLID STATE
DIVISION 8

INTRODUCTION

This abbreviated report covers the work of Division 8 from 1 May through 31 July 1965. A more detailed presentation is covered by the Solid State Research Report for the same period.

H. C. Gatos
Head, Division 8

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DIVISION 8 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1965

PUBLISHED REPORTS

Journal Articles*

JA No.			
2399	Galvano-Thermomagnetic Phenomena and the Figure of Merit in Bismuth. I. Transport Properties of Intrinsic Material	T.C. Harman J.M. Honig B.M. Tarmy	Adv. Energy Conversion 5, 1 (1965), DDC 618461
2454	Resistivities and Transformation Rates of High-Pressure InSb-β Sn Alloys	M.D. Banus L.B. Farrell A.J. Strauss	J. Appl. Phys. 36, 2186 (1965)
2480	Partial Pressures of Hg(g) and Te_2(g) in the Hg-Te System from Optical Densities	R.F. Brebrick A.J. Strauss	J. Phys. Chem. Solids 26, 989 (1965)
2535	Higher Order Corrections to the Molecular-Field Theory of the Magnetic State	G.F. Dresselhaus	Phys. Rev. 139, A855 (1965)
MS-1116	Transition-Metal Oxides with Metallic Conductivity	J.B. Goodenough	Bull. Soc. Chim. France, No. 4, 1200 (1965), DDC 618458

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
2525	Interband Magneto-Optical Effects	B. Lax J.G. Mavroides	Accepted for Vol. 2, Physics of III-V Compounds, R.K. Willardson and A.C. Beer, Editors (Academic Press, New York)
2550	Spin Orbit Interaction in Graphite	G.F. Dresselhaus M.S. Dresselhaus	Accepted by Phys. Rev.
2556	Long-Range Exchange Interactions from Spin Wave Resonance	R. Weber P.E. Tannenwald	Accepted by Phys. Rev.
2588	Quenching of Dy^{+2} Fluorescence by Y^{+2} in CaF_2:Dy^{+2} Lasers	J.R. O'Connor	Accepted by Appl. Phys. Letters

* Reprints available.

Unpublished Journal Articles (Continued)

JA No.			
2589	Effect of Y^{+3} on the Reduction of Sm^{+3} in CaF_2	J.R. O'Connor R.M. Hilton	Accepted by Appl. Phys. Letters
2590	Simple Apparatus for Applying Uniaxial Pressure at Cryogenic Temperatures	J.H.R. Ward	Accepted by Rev. Sci. Instr.
2597	The Bohr-Sommerfeld Quantization Rule and the Weyl Correspondence	P.N. Argyres	Accepted by Physics
2599	High-Field Magnetoabsorption of the Indirect Transition Exciton in Germanium at 1.7°K	J. Halpern B. Lax	Accepted by J. Phys. Chem. Solids
2600	Partial Pressure of Se_2 and Optical Density of Selenium Vapor in the Visible Ultra-Violet	R.F. Brebrick	Accepted by J. Chem. Phys.
2604	PbS Diode Laser	J.F. Butler A.R. Calawa	Accepted by J. Electrochem. Soc.
2605	Electrical Properties of Metal Oxides Characterized by "Hopping" Charge Carriers	J.M. Honig	Accepted by J. Chem. Educ.
2629	Physics of Quantum Electronics – A Conference Report	P.E. Tannenwald P.L. Kelley B. Lax	Accepted by Phys. Today
Galvano-Thermomagnetic Phenomena with Applications to Energy Conversion		T.C. Harman J.M. Honig	Accepted by McGraw-Hill, New York

Meeting Speeches*

MS No.			
1134A-B	Chemical Uses of Induction Plasmas	T.B. Reed	United Aircraft Research Laboratories, East Hartford, Connecticut, 27 May 1965; Stanford Research Center, Stanford, California, 13 May 1965
1243F-H	Recent Advances in Semiconductor Lasers	R.H. Rediker	Seminar, University of Southern California, Los Angeles, 15 July 1965; Seminar, Aerospace Corporation, El Segundo, California, 16 July 1965; Seminar, Eastman-Kodak, Rochester, New York, 30 July 1965

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Unpublished Meeting Speeches (Continued)

MS No.			
1245A-B	Recent Developments in Crystal Growth	T.B. Reed	Arizona State University, 6 May 1965; University of Arizona, 7 May 1965
1253	Intricately-Shaped Semimetal Samples by Spark Erosion	S. Fischler M.J. Button	Electrochemical Society Semiconductor Sessions, San Francisco, 13 May 1965
1293	Spin Orbit Interaction in Graphite	G.F. Dresselhaus M.S. Dresselhaus J.G. Mavroides	Seventh Biennial Conference on Carbon, Cleveland, Ohio, 21-25 June 1965
1294	Energy Band Parameter Determination in Graphite	M.S. Dresselhaus J.G. Mavroides	
1339	Amplitude Noise in Gas Lasers Below and Above the Threshold of Oscillation	C. Freed H.A. Haus*	Physics of Quantum Electronics Conference, San Juan, Puerto Rico, 28-30 June 1965
1343	Sum and Difference Frequency Generation in Gases and Liquids	P.N. Butcher* W.H. Kleiner P.L. Kelley H.J. Zeiger	
1396	Magneto-Emission Studies of PbS, PbTe, and PbSe Diode Lasers	J.F. Butler A.R. Calawa	
1397	Laser Emission by Optical Pumping of Semiconductors	R.J. Phelan, Jr.	
1398	Multiple Stimulated Brillouin Scattering in Solids	P.E. Tannenwald	
1399	Plasmon Scattering of Light and Stimulated Emission of Plasmons in Solids	A.L. McWhorter	
1341	Focusing Far Infrared Reflection Filters	D.H. Dickey	20th Annual Molecular Spectroscopy Symposium, Columbus, Ohio, 14-18 June 1965
1346	Oscillatory Faraday Rotation of the Direct Transition in GaSb at 1.5°K	J. Halpern	American Physical Society, New York, 23-25 June 1965
1357A	Thermodynamics of Semiconducting Tellurides	R.F. Brebrick	IRIS Specialty Group, Syracuse University, 15 June 1965

* Author not at Lincoln Laboratory.

Unpublished Meeting Speeches (Continued)

MS No.			
1382	Pressure Tuned Lead Salt Laser	J.M. Besson* J.F. Butler A.R. Calawa W. Paul* R.H. Rediker	1965 Solid-State Device Research Conference, Princeton University, 21-23 June 1965
1383	Electrical and Electro-Optical Properties of GaAs-InSb "Schottky" Barrier Heterojunctions	E.D. Hinkley R.H. Rediker	
1384	Transients and Hot Carrier Effects in InSb Bulk Injection Lasers	I. Melngailis	
1385	Properties of Optically Pumped Semiconductor Lasers	R.J. Phelan, Jr.	
1388	High Electric Field and Pressure Effects in n-CdTe, n-InAs and n-InSb	A.G. Foyt W. Paul* A.L. McWhorter	
1387, 1387A	Helicon Instabilities in Drifted Plasmas	A. Bers* A.L. McWhorter	1965 Solid-State Device Research Conference, Princeton University, 21-23 June 1965; 1965 Conference on Electron Device Research, University of Illinois, 23-25 June 1965
1389	Effect of Pressure on Electrical Properties of Some $A^{III}B^{VI}$ Compounds	M.D. Banus	Symposium, New York University, 13 May 1965
1394	Magneto-Optical Effects in Solids	G.F. Dresselhaus	Lecture Series, Optical Properties of Solids, Enrico Fermi School, Varenna, Italy, 28 June – 9 July 1965
1422	Theory of the Method of Kinetic Equations for Quantum Systems	P.N. Argyres	Lecture Series, Summer Institute for Theoretical Physics, University of Colorado, 14-25 June 1965
1425	Directed Heating with Atoms, Electrons, and Photons	T.B. Reed	American Cyanamid Company, Stamford, Connecticut, 17 June 1965
1428	Magnetospectroscopy in Solids	J.G. Mavroides	Lecture Series, University of California, Los Angeles, 19-30 July 1965
1429	Magnetospectroscopy in Solids	J.O. Dimmock	

* Author not at Lincoln Laboratory.

Unpublished Meeting Speeches (Continued)

MS No.			
1449	Gunn Effect in Compound Semiconductors	A. L. McWhorter	Gordon Research Conference on Chemistry and Metallurgy of Semiconductors, Andover, New Hampshire, 16 July 1965
1450	Recent Advances in Semiconductor Lasers	A. L. McWhorter	

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Photoluminescence spectra of bulk InSb pumped with the output from a GaAs laser have been used to identify the band-to-band radiative transition as well as transitions from the conduction band to zinc acceptor levels and to cadmium acceptor levels. Diode lasers, as well as optically pumped n-type bulk lasers, have involved band-to-band emission. Optically pumped p-type bulk lasers have been fabricated from cadmium-doped samples and have involved transitions to the cadmium acceptor levels. The most efficient material for optically pumped bulk-laser action has been pure n-type ($n = 10^{14} cm^{-3}$). Pumping a surface at right angles to the cavity axis produced beam angles which imply active regions of about 40 μ in diameter. Thus, although the GaAs radiation is expected to penetrate only about 1 μ into the InSb, the diffusion length of the electrons and holes is such as to spread the recombination region over a much greater volume. Greater efficiencies and lower thresholds have been obtained by decreasing the sample thickness. If the surface recombination can be kept low, with thicknesses shorter than a diffusion length, much larger equilibrium densities can be obtained for a given incident pump flux density, and some of the lossy regions are eliminated from the material. For a 50-μ sample, the threshold for laser action (converting the absorbed power into an equivalent injection current) at 10°K corresponded to about 100 amp cm^{-2}, a factor of 10 less than that obtained with InSb diode lasers without a magnetic field. Because the surfaces of the sample were etched to keep surface recombination low, they are quite rough and the beam angles have exceeded the dewar window aperture; however, the external quantum efficiency of the spontaneous emission, assuming the sample to radiate isotropically (no deviation was measurable over the 1-sr optical access) is about 50 percent. It is apparent that the large diffusion lengths, although they may limit the threshold power density, may be used to obtain laser action from large volumes and with a longitudinal type structure with the pumping beam incident upon one large area face of a semiconductor and the laser emission emerging from the opposite, parallel face.

Present InAs diode lasers which emit near 3.1 μ (band-to-acceptor line) have external quantum efficiencies of about 12 percent and threshold current densities of about 300 amp cm^{-2} at 11°K, and they can be operated continuously with currents of several amperes. With magnetic fields of several kilogauss applied perpendicular to the diode current, the threshold has been further reduced and the efficiency increased to as much as 25 percent. This enhancement of emission is shown to be associated with a decrease of injected carrier diffusion in the magnetic field, which produces a more compact active region. The threshold increases nearly exponentially with temperature up to 150°K, the highest temperature for InAs laser action at present.

The output wavelength of the coherent and spontaneous emission from PbSe diode lasers operating at 77°K has been tuned from 7.3 to 11.2 μ by applying hydrostatic pressure up to 7 kbars. The pressure variation of the photon energy of the emitted radiation is -8.5×10^{-6} ev/bar, in substantial agreement with the pressure coefficient of -9×10^{-6} ev/bar of the optical

absorption edge. As in the case of magnetic and temperature tuning, pressure tuning of the laser emission involves small changes in the wavelength of the excited cavity modes and switching of these modes, so that the dominant mode varies as above. The individual modes shift at the rate of 2.5×10^{-6} ev/bar at 400 bars, and 1.6×10^{-6} ev/bar at 6.5 kbars. This shift, caused by the change in optical length of the Fabry-Perot cavity, corresponds to a relative variation (1/n) (dn/dP) of about 1.3×10^{-5} bar^{-1}. With diode current held constant, we have observed no significant change in intensity of the coherent or spontaneous emission with pressure. Extension of this work to 13 kbars, the freezing pressure of helium at 77°K, should be a straightforward task requiring the development of a suitable window transparent to about 21 μ. Higher pressures will require new techniques, but we feel that extension to 20 kbars, the pressure at which the energy gap of PbSe is expected to close at 77°K, is possible.

Magnetoemission experiments reported previously for PbSe and PbTe diode lasers have been further refined and also have been extended to PbS diode lasers. For these PbS diodes, the shift in the spontaneous emission peak with magnetic field is consistent with a value for the reduced effective mass of 0.05 m_o, and g values $|g_v| = 7.0$ and $|g_c| = 11.5$, all values being for the [100] direction. From the shift of the individual modes with magnetic field, the magneto-dispersion $(\partial n/\partial H_{[100]})_E$ for PbSe and PbTe are -1.3×10^{-6} $gauss^{-1}$ and -1.2×10^{-6} $gauss^{-1}$, respectively.

Experimental results on the Gunn effect in n-GaAs support the transferred electron model of Ridley and Watkins as the model for this effect. The bulk negative resistance that results if the transfer occurs rapidly enough as the electric field is increased, leads to the formation of domains of different electrical conductivity which move through the sample. The shape of the current-time waveform for the longer samples ($\ell \sim 100$ to 1000 μ) – sharp spikes in current separated by flat valleys in current – and the observed independence of threshold electric field (2300 to 4000 volts/cm) on sample length are consistent with a negative-resistance model. The value of electric field which characterizes the regions of high conductivity, about 1500 volts/cm, is independent of sample length, as expected. In addition, the voltage across the high electric field domain scales with sample length (also as expected) and the value of electric field which characterizes the regions of low conductivity is estimated to be $\geq$60,000 volts/cm. The effect of temperature on the threshold electric field and threshold electron drift velocity is consistent with the transferred electron model. For short samples ($\ell \sim 25$ to 100 μ), a sinusoidal current-time waveform is seen; for samples in the 100-μ length range, the sinusoidal mode is seen near threshold and the spike mode is seen well above threshold. Although the sinusoidal mode is not predicted by the simplest form of the model, the effects of magnetic field and termination impedance on this mode are consistent with the interpretation of this mode as a longitudinal disturbance caused by a negative resistance. The Gunn effect has also been observed in n-CdTe, and resistance vs hydrostatic pressure experiments show that the transferred electron model is a reasonable explanation for this material as well. Finally, the absence of an instability in n-InSb and n-InAs is shown to be consistent with the detailed band structure of these materials and the transferred electron model.

II. LASER RESEARCH

Laser beam perturbation of the refractive index of absorbing media has been studied further. In the recent work, ammonia gas is used in place of the liquid material previously studied. By utilizing a neodymium laser for the perturbing beam and a pulsed argon laser as the interferometer source, the fringe shift (or change in optical path length) has been correlated with the energy deposition across the area of the neodymium beam. The measured changes in index of refraction are approximately 1.7 times greater than would be predicted from a simple theory. Q-switched operation of the neodymium source leads to similar results, indicating that the fringe shifts are determined only by the total energy deposited and are not power dependent.

Electron densities in an argon ion laser have been measured by observation of the Stark broadening of particular neutral argon lines. Densities of 10^{13} to 10^{14} cm^{-3} have been measured over the range of currents used. These densities have, in turn, been correlated with the stimulated and spontaneous emission and the voltage across the tube.

The high-pressure mercury laser system has been further tested without successful oscillation. The negative results are attributed to insufficient gain as calculated from the measured spontaneous emission.

The photocurrent spectrum and photoelectric counts produced by a gaseous laser have been measured. Using a semiclassical theory of the Van der Pol oscillator, good agreement is found between the experimental and theoretical values of the three lowest-order factorial moments of the photocount distribution.

Multiple stimulated Brillouin scattering has been measured in quartz using a ruby laser. As many as six successive Brillouin shifts have been observed as a result of iterative scattering and reamplification in the ruby rod. Only Stokes waves are generated in the experiment, which can be explained by considerations of the Brillouin conversion efficiency and ruby gain.

III. MATERIALS RESEARCH

Single crystals of zinc aluminate doped with approximately 0.1-percent Co^{+2} have been grown from a flux of lead oxyfluoride. The crystals, which are blue and transparent, will be used for measurements of the nuclear hyperfine field of tetrahedrally coordinated Co^{+2}.

Conductivity measurements have been made between 120° and 670°K on single crystals of $LaVO_3$ and YVO_3 obtained by slow cooling of the melts in iridium crucibles, and magnetic susceptibility measurements are being made on powders prepared from the crystals. The data indicate that the t_{2g} state of V^{+3} in these rare earth perovskites exists as discrete levels, without bands being formed. Preliminary results indicate the existence of an antiferromagnetic transition in $LaVO_3$ at $T_N \approx 135°K$.

According to a tentative stability diagram which has been obtained for perovskite phases in the La-Mn-O system, these phases exist over wide ranges of composition. The diagram shows that the amount of Mn^{+4} in a particular sample depends sensitively on the conditions of preparation as well as on the ratio of La to Mn.

The results of high-temperature x-ray diffraction measurements on powdered $LaCoO_3$ show that the semiconductor $\rightleftarrows$ metal transition which occurs at 1210°K is accompanied by a change in space group from $R\bar{3}$ below this temperature to $R\bar{3}m$ above it. Between 600° and 1210°K, the degree of order increases with increasing temperature.

The accuracy with which crystallographic parameters can be calculated from x-ray diffraction data has been markedly improved by applying the simplex method for minimizing the differences between experimental and computed values of observable quantities. Computer programs using this method have been written for calculating cell edge values from 2Θ data, and for calculating atom positions from line-intensity data.

Crystallographic parameters for 10 spinels of the type ACr_2X_4 (where A = Mn, Fe, Co, Cu, Zn or Cd, and X = O, S or Se) have been calculated by the simplex method from x-ray diffraction data on powdered samples. Comparison with neutron diffraction results indicates that standard x-ray powder measurements can yield crystallographic parameters comparable in accuracy to those obtained by neutron diffraction experiments.

In order to obtain calibration data for determining selenium partial pressures over HgSe(c) and other binary selenides, the optical density of Se vapor in equilibrium with pure liquid Se has been measured between 1900 Å and 2.0 μ for total Se pressures between 7×10^{-5} and 1.0 atm. The partial pressures of Se_2 obtained from the data agree closely with those calculated from the dissociation constants for Se_4, Se_6 and Se_8 reported by Illarionov and Lapina.

The resistivity and Hall coefficient of oriented Ti_2O_3 single crystals have been measured between 4.2° and 390°K at magnetic fields between 8 and 170 kG. Neither property changes appreciably with sample orientation. This lack of anisotropy is inconsistent with a proposed band model which ascribes band formation near the Fermi level exclusively to direct cation-cation interactions.

The similarity between high-pressure InSb(II) and β-Sn is being explored by studying the InSb(II)-In system, in order to compare its properties with those of the Sn-In system. Initial measurements on $InSb(II)_{1-x}(2\ In)_x$ samples, with x between 0.1 and 0.5, suggest the existence of a phase analogous to the Sn-rich γ phase in the Sn-In system.

Experiments on $CaF_2:Dy^{+2}$ lasers containing different concentrations of Y have shown that Y^{+2} quenches the fluorescence of Dy^{+2} and therefore raises the threshold for laser action. The results of fluorescent lifetime measurements show that quenching is caused by resonant energy transfer between the $^5I_7$ level of Dy^{+2} and excited t_{2g} levels of Y^{+2}.

IV. PHYSICS OF SOLIDS

Reflectivity measurements in single crystals of rhenium trioxide in the vicinity of 2.3 ev indicate a steep plasma edge which is reminiscent of silver and which may therefore arise from a similar mechanism, namely competing intraband and interband processes.

Oscillatory magnetoabsorption and Faraday rotation studies at 1.5°K and up to magnetic fields of 103 kG are being carried out in single crystals of a number of semiconductors. The indirect edge is being examined in germanium, while oscillatory effects due to direct transitions are being studied in gallium antimonide and gallium selenide.

In the continuing optical study of sulfur-doped silicon, a fourth impurity center has been found (in addition to those previously reported). This center, which is presumed to be due to pairs of neutral sulfur atoms, exhibits a spectrum under stress with unexpected extra splittings.

A more direct determination of the spin-orbit band splitting ϵ_{so} has been made in graphite by use of the magnetoreflection data. The result $\epsilon_{so} = 0.005 \pm 0.002$ ev is greater by at least one order of magnitude from previous estimated values but comparable to that measured by Rauch in diamond, $\epsilon_{so} = 0.006$ ev.

A study of the behavior of the excitation spectra of group III impurities in germanium under uniaxial stress has been completed. The various experimental lines have been identified from line intensities and polarization effects. Deformation potentials for the valence band have been determined.

Measurements of the microwave surface impedance in p-type PbSe, in the Azbel-Kaner geometry, as a function of magnetic field at 70 kMcps have indicated complicated hybrid resonances as well as magnetoplasma effects. In order to simplify the data, and hence the theoretical interpretation, a new cavity is being constructed which should provide a better control between the relative orientations of the RF electric field and the DC magnetic field.

Helicon wave propagation is being studied in single crystals of lead telluride at 9 kMcps, at 4.2°K and with magnetic fields up to 10 kG. The measured anisotropies of the complex propagation vector should provide information on the effective mass and collision time anisotropies.

Microwave phonon generation work at 70 kMcps is continuing. By using a combination of a better sample, as well as an improved cavity, the number of echoes which can be observed has been doubled so that now eight to ten echoes are observed; thus, the T^4 temperature dependence of the attenuation in x-cut quartz has been confirmed with an improved accuracy.

The propagation of microwave phonons (9 kMcps) is also being studied in pure semiconductors at low temperatures where electron-phonon scattering is the predominant hypersonic attenuation mechanism. Extremely sensitive measurements can be made of the magnetic field dependence of both the attenuation and velocity. The performance of the microwave detection system has been verified by using GaAs single-crystal samples and also x-cut quartz.

Spin wave dispersion experiments on permalloy (63% Ni-27% Fe) films have been extended to low temperatures. These studies, which have now been carried out at 4.2°, 77° and 298°K on the same sample, indicate that the long-range interaction distance is approximately one order of magnitude larger than the nearest-neighbor distance, and that the coefficient of the quartic term is roughly (within 20 percent) temperature independent.

Magnetic studies are being extended to chromium spinels with nonmagnetic A-sites. One interesting material being measured is the cubic spinel $CdCr_2Se_4$, which has been found to be ferromagnetic and also nonconducting. Thus, this compound offers a rather unique theoretical opportunity for comparison with the Heisenberg model of ferromagnetism.

Studies are being made of the variation of thermoelectric power with hydrostatic pressure in extrinsic n-type HgSe, HgTe, and $HgSe_xTe_{1-x}$ alloys. These measurements are being used to supply evidence for the relative ordering of the Γ_6 and Γ_8 energy states.

For T = 0°K, the numerical calculation of the magnetic field dependence of the energy and linewidth of the transition between the n = 0 and n = 1 Landau levels of a piezoelectric polaron has been completed; the effect is found to be very small. However, a similar evaluation for the optical polaron indicates a considerably larger nonlinear magnetic field dependence which may be experimentally observable.

The nonrelativistic augmented plane wave (APW) technique has been used to calculate the electronic band structure of the rare-earth metals gadolinium, thulium and lanthanum, and also palladium metal. The rare-earth calculations account for the bandwidth of the 4f band in gadolinium as measured in photoemission experiments and also the exchange splittings of the s-d conduction bands. Further predictions have been made concerning the expected optical

properties in the visible and ultraviolet. In palladium, a Fermi surface consisting of two hole surfaces and a compensating electron surface has been calculated; good agreement is found with the results of the de Haas-van Alphen data.

It has generally been assumed that the Hartree-Fock ground state of closed shell atoms and atomic ions always has the ^1S symmetry of the exact ground state, although recently this has been questioned. It is shown here that this assumption is not generally correct, which implies that the Hartree-Fock theory for such systems should now be reinvestigated and raises fundamental questions about the meaningfulness of "correlation" corrections as usually defined, and hence about criteria for the importance of such corrections.

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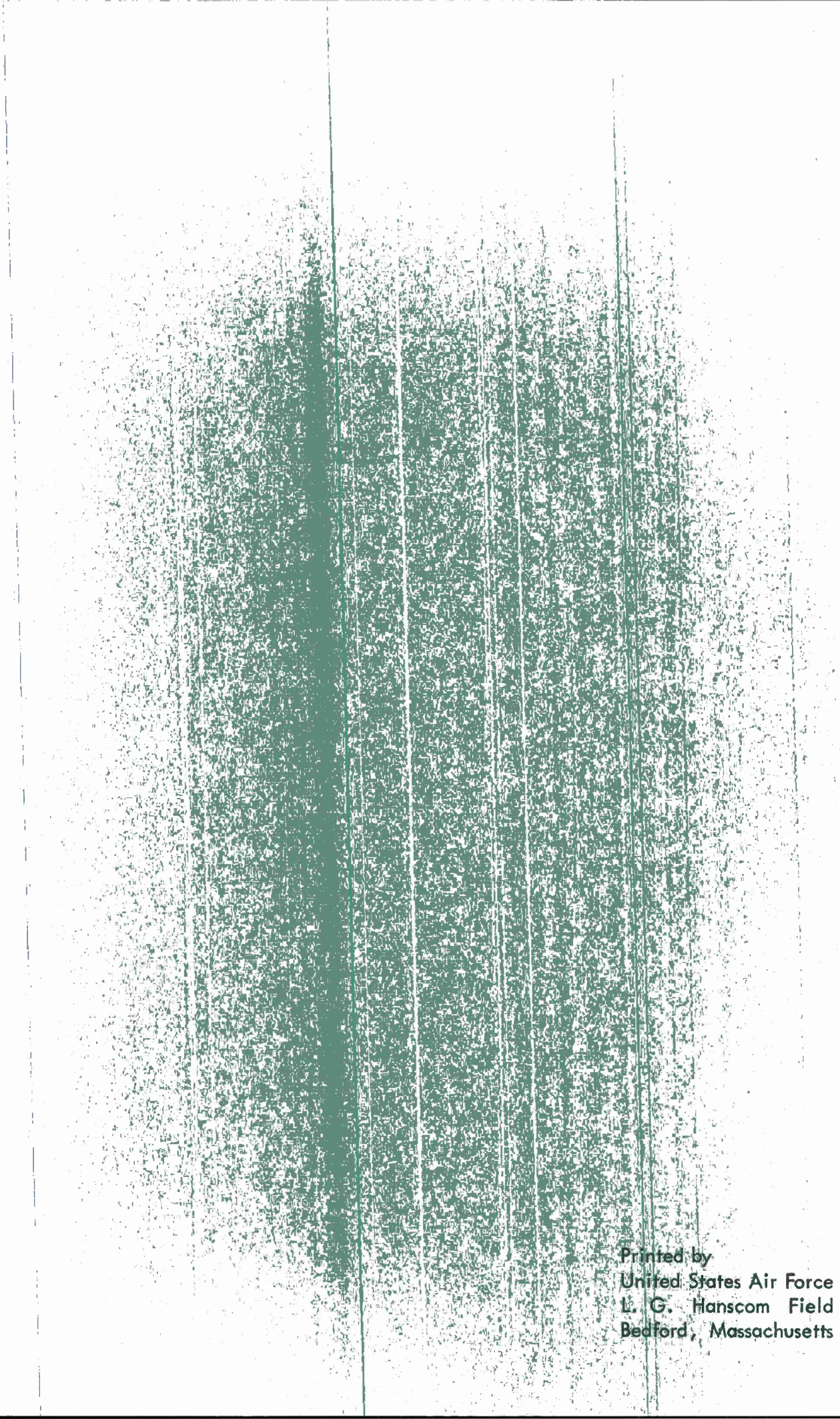

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